Review

America's Obesity Epidemic: Measuring Physical Activity to Promote an Active Lifestyle

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ABSTRACT
The incidence of overweight and obesity in the United States and worldwide has reached epidemic proportions. To effectively intervene, dietetics professionals and other health care practitioners need to address both sides of the energy balance equation when counseling clients and patients. Often, the focus on energy intake supersedes the promotion of a physically active lifestyle. Incorporating appropriate and sufficient physical activity into one's life is an essential component of achieving and maintaining a healthful body weight. This review summarizes background knowledge on the benefits of physical activity for health and provides an overview of available tools for measuring physical activity and energy expenditure. The physical and mental health benefits of an active lifestyle, current physical activity recommendations for the US public, the prevalence of inactivity in the United States, and components of energy expenditure are reviewed. Additionally, tools for estimating total energy expenditure, resting metabolic rate, and physical activity are evaluated and suitable approaches for applying these tools are provided.
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Physical inactivity and poor diet have been identified as a leading cause of death in the United States. In 2000, about 400,000 deaths were linked to these behaviors (1). This figure represents a 33% increase in deaths attributable to these behaviors since 1990 (2) and the prevalence of overweight and obesity is considered to be the major mediator of this increase. If the trend of escalating overweight and obesity is not reversed in the near future, the combination of poor diet and inactivity may become the number-one cause of death (1). These sobering statistics demand the attention of all health care practitioners but they represent a specific call to action for dietetics professionals. To effectively move forward, practitioners need to be equipped with both knowledge and appropriate tools. Often, health care professionals focus heavily on the energy intake side of the energy balance equation. However, emphasis on both energy intake and expenditure is needed to address the current obesity epidemic. The purpose of this review is to provide essential background knowledge and an overview of available tools for practitioners to use with clients or patients. Tools for estimating total energy expenditure (TEE), resting metabolic rate (RMR), and physical activity are reviewed.

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HEALTH BENEFITS OF PHYSICAL ACTIVITY

Traditionally, exercise has been viewed as a universal panacea, providing a wide range of both physical and psychological benefits. Moderate amounts of physical activity have been shown to reduce the risk of premature mortality from all causes (3), and from coronary heart disease specifically (4). Numerous studies have linked regular physical activity with improvements in the function of muscles and joints, achieving peak bone mass, fine-tuning metabolic homeostasis, achieving endocrine and immunologic health, and enhancing mental heath. In the Dietary Guidelines for Americans (5), the importance of regular physical activity is highlighted in the overall recommendation to aim for fitness, and the recognized health benefits of regular physical activity are outlined (Figure 1). In recent years, it has also become apparent that regular physical activity, including activities not traditionally classified as exercise such as leisure-time and work-related activities, may also yield health benefits. Research has supported the idea that habitual physical activity is inversely related to the incidence of obesity, type 2 diabetes mellitus, and cardiovascular disease.

Obesity

When energy intake exceeds energy expenditure, the surplus energy is stored, primarily as body fat. If this positive energy balance occurs chronically, obesity develops. Increasing physical activity to achieve energy balance and prevent obesity, rather than solely reducing energy intake, offers several physiologic and metabolic advantages. Physical activity may improve appetite control, but this is a largely unexplored area of research, and most of the studies have examined only the acute or short-term effects of exercise on food intake (6). Longer-term studies

- Increases physical fitness
- Helps build and maintain healthy bones, muscles, and joints
- Builds endurance and muscular strength
- Helps manage weight
- Lowers risk factors for cardiovascular disease, colon cancer, and type 2 diabetes
- Helps control blood pressure
- Promotes psychological well-being and self-esteem
- Reduces feelings of depression and anxiety

Figure 1. Health benefits of regular physical activity (5).

monitoring appetite and food intake in response to regular physical activity have yet to be conducted. Regular physical activity is known to induce favorable metabolic changes in muscle and adipose tissue that promote the use of fat for energy as opposed to storing it. These changes are summarized in detail in reviews by Faulkner and colleagues (7) and Despres (8).

Type 2 Diabetes

Physical activity enhances insulin sensitivity and improves glucose tolerance (9). Hence, research efforts have been directed toward defining the role of physical activity in the prevention and treatment of type 2 diabetes mellitus. Increased incidence of type 2 diabetes has been linked to inactivity in large population studies (10-12), and participation in lifestyle modification programs to increase physical activity leads to a reduced incidence of the disease (13,14). Improved insulin sensitivity has also been reported in persons with diabetes who become more physically active (15,16). These positive effects of physical activity may be attributed, in part, to increased skeletal muscle contractions that mimic the action of insulin, thereby increasing glucose uptake and metabolism (17-19).

Cardiovascular Disease

The relationship between physical activity and cardiovascular disease has been an active area of investigation for many years. Engaging in regular exercise or moderate physical activity improves circulating lipid profiles and favorably alters lipoprotein metabolism (20-23), decreases blood pressure (24), reduces blood coagulation and platelet aggregation (25), and decreases risk of cardiac arrhythmias (26). The prevention of cardiovascular disease by physical activity has been recently reviewed (27).

Mental Well-Being

Psychological benefits of long-term exercise participation have been observed (28-32). Physical activity appears to help in managing mild to moderate depression and anxiety, but there is less evidence to support its effect on more severe anxiety disorders. Cross-sectional and prospective studies generally demonstrate that higher levels of occupational and leisure time physical activity are associated with reduced symptoms of depression, with the effects tending to be stronger in women than in men. Inactive persons are about twice as likely to have symptoms of mild to moderate depression than persons who are more active. However, observational studies are inadequate for determining if physical inactivity leads to symptoms of depression; if symptoms of depression lead to inactivity; or if some other factor, such as social support, might mediate the relationship. Interventional studies are required for this purpose. To date, evidence from randomized controlled trials supports the prior findings, and further suggests that moderate- and vigorous-intensity aerobic or resistance-training exercise can reduce symptoms of depression. Unfortunately, such studies have not systematically investigated the type of exercise or the duration and intensity of exercise required to reduce symptoms of depression. Further, the literature is equivocal about whether or not increases in cardiorespiratory fitness are required to alter symptoms of depression. Proposed underlying mechanisms believed to mediate these beneficial effects include both physiologic and psychological factors such as endorphins, distraction, and feelings of self-efficacy.

Cognitive Function

Studies also suggest that physical exercise can benefit cognitive functioning, particularly in later life. There is now a substantial body of literature suggesting that lifelong, regular exercise can result in cognitive enhancements (33). Much of the literature has focused on aerobic exercise such as walking, running, bicycling, and swimming. A recent meta-analysis indicates that aerobic fitness training can have a robust and beneficial influence on the cognition of older adults, regardless of the type of cognitive task, the training method, or the participants' characteristics (34). Interestingly, a regimen that combined strength and aerobic training had a stronger effect on cognitive performance than did aerobic training alone. However, only long-term adherence (more than 6 months) to a regular exercise regimen, lasting about 45 to 60 minutes at each session, was found to be effective. Cognitive processes, such as planning, scheduling, coordination, inhibition, and working memory exhibited the most benefit with improved fitness. Animal research supports these findings (35-37) and further demonstrates that exercise stimulates the adult and aging brain to generate new neurons, to promote functional changes in neuronal structure, to elevate neuronal resistance to injury, and to increase brain vascularization (36,38). All of these factors likely play a role in the enhancing effects of exercise on human cognitive performance.

RECOMMENDATIONS TO THE PUBLIC

For almost 40 years, a clear message has been sent to the public regarding the need to be physically active. However, general recommendations emphasizing the use of endurance-type exercises for preventing heart disease (39), improving cardiorespiratory fitness (40,41), promoting health (42), and controlling weight (43) have now evolved to more outcome-specific advisories.

Prevention of Chronic Diseases

In 1996, the Surgeon General issued *Physical Activity and Health* (29), a report stating that persons of all ages should accumulate a minimum of 30 minutes of physical activity of moderate intensity on most, if not all, days of the week. This amount of physical activity is roughly equivalent to expending 150 kcal per day or 1,000 kcal per week. The primary outcome affected by this quantity of physical activity is decreased risk of developing chronic diseases such as diabetes and cardiovascular disease. The report also acknowledges that for most, greater physical health benefits and weight control can be obtained by engaging in physical activity of more vigorous intensity or of longer duration, and that exercises to develop strength should be performed at least twice weekly for adults.

Weight Control

More definitive recommendations are needed if the desired outcome is to be related to weight control (ie, weight loss, maintenance of reduced body weight, or prevention of adult weight gain). Physical activity is recognized as an important component of weight-loss programs but is most effective when combined with appropriate diet modifications (44). To prevent weight regain following significant weight loss, estimates of physical activity energy expenditure have been reported to range between 300 and 400 kcal per day (45-48). Clearly, these values for physical activity energy expenditure exceed the current public health recommendations and underscore that a higher level of participation in a physically active lifestyle is required to maintain a reduced body weight.

Prevention of Adult Weight Gain

It is important to know how much physical activity is required to prevent unhealthful weight gain in adults. Observational evidence indicates that regular physical activity can prevent weight gain, but it must be moderate to vigorous in intensity and associated with improvements in physical fitness (49). A comprehensive review of the evidence suggests that the energy expended in daily physical activity be at least 80% of resting energy expenditure, an activity level equivalent to an additional 60 to 90 minutes of brisk walking in adults who normally engage in only modest amounts of physical activity (50). These physical activity recommendations coincided with the release of the Dietary Reference Intakes for energy and macronutrients (51). The recommendation of 30 minutes per day of regular, moderate-intensity activity was challenged because it was insufficient to prevent adult weight gain and fully achieve all the identified health benefits. Instead, the recommendation is that adults should engage in 60 minutes of moderate-intensity physical activity daily to promote a healthful body weight as well as health and vigor (51).

Television Watching

Policy makers who are promoting an increase in physical activity should not ignore the independent impact of a sedentary lifestyle on health and disease prevention. Measures of sedentary behavior, such as hours spent watching television, have been used in several large population studies and, as expected, are associated with an increased risk of becoming overweight or obese (52,53), as well as developing type 2 diabetes mellitus (54,55) or cardiovascular disease (56). Television viewing appears to have the strongest association with obesity compared with other sedentary behaviors such as reading, working at a computer, or commuting in a car. This finding may be attributable to the facts that the least amount of energy is expended during television viewing compared to other common sedentary behaviors, increased snacking of energy-dense foods may occur during television viewing, and persons with the highest television viewing time also tend to have the poorest diet quality (55). It is interesting to note that in large population studies there was no association between hours spent watching television and physical activity levels; both television viewing and physical activity level contributed independently to risk of developing obesity and type 2 diabetes (55). Even in the most physically active people, incidence of overweight increased as the hours of television viewing increased (57). These findings imply that higher levels of regular physical activity do not guarantee that persons will reduce the time spent in sedentary behavior. Hence, increased physical activity may not provide the expected health benefits if sedentary behaviors persist. Not only should public health messages encourage increased physical activity, but they should also aim to decrease time spent in sedentary behaviors by suggesting other lifestyle choices that involve moving more and sitting less, such as walking or bicycling to work, walking pets, walking at the mall, using stairs instead of elevators, increasing time spent in household tasks, gardening, and taking activity breaks at work.

PREVALENCE OF INACTIVITY

Efforts to track physical activity and sedentary behaviors have been standardized and allow assessment of the prevalence of inactivity across the United States (Figure 2). Data obtained in 2001 from the Behavioral Risk Factor Surveillance System indicate that only 22% of US adults are achieving the recommended amount of regular physical activity, more than 60% of US adults are not physically active on a regular basis, and 25% of all adults are not active at all. Physical inactivity was more prevalent among women than men, older than younger adults, less affluent than more affluent, and African-American or Hispanic ethnicity than white ethnicity (29). Although it would seem logical to conclude that physical activity levels have declined as the incidence of obesity has increased, most observational data indicate that physical activity levels, particularly the time spent in leisure activities, have not changed during the escalation of the obesity epidemic (58). This conclusion might be erroneous because the emphasis has been placed on monitoring leisure-time activities, and many physical activity changes related to occupational, household, and miscellaneous categories of activity have not been well characterized. With better standardization of surveillance methodology and improved tools for assessment of energy expenditure and physical activity, we will be better equipped to define the relationship among physical activity, sedentary behavior, and obesity and associated chronic diseases.

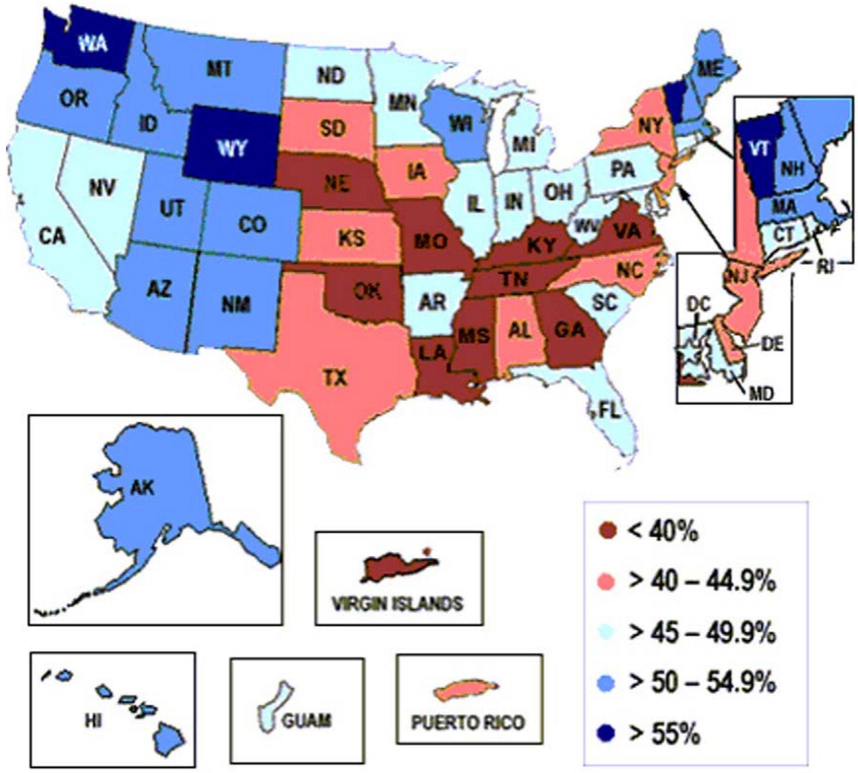

Figure 2. Prevalence of people in each state meeting public health physical activity recommendations (at least 5 days a week, 30 minutes a day of moderate activity or at least 3 days a week, 20 minutes a day of vigorous activity). Figure courtesy of US Centers for Disease Control and Prevention.

A PRIMER ON ENERGY EXPENDITURE

Components of Energy Expenditure

TEE, measured over a 24-hour period, has several components. The basal metabolic rate (BMR) represents the minimal rate of energy expenditure that is needed to support vital functions such as the work of breathing, circulation of blood, contractions of the gastrointestinal tract, maintenance of body temperature, metabolic homeostasis at rest, and other functions of internal organs. BMR measurement requires that the subject be in a supine position, following a 12-hour fast, in the morning (30 minutes after awakening but before rising out of bed), in a thermoneutral environment with dim lighting, low noise level, and minimal distractions. Because of the challenges associated with establishing these conditions, RMR is measured more frequently. RMR represents the amount of energy expended under restful conditions, and typically accounts for about 60% to 70% of TEE. Typically, RMR is measured after 30 minutes of rest in a recumbent position. In a research protocol, an RMR measure occurs under fasting conditions (10 to 12 hours), with no participation in strenuous physical activities for 24 to 48 hours before measurement. These stringent conditions are often not feasible in a clinical setting, and RMR measures are taken in the postabsorptive state (approximately 4 hours following the most recent meal) with no limit placed on strenuous physical activity on days preceding the measurement. Additional procedures that might be stressful or agitate the patient, such as blood drawing, must also be avoided whenever possible. When measured under these less rigorous conditions, RMR is approximately 10% higher than BMR. The thermic effect of food, or dietary thermogenesis, is the component of TEE that represents the energy needed for eating, digesting, absorbing, transporting, metabolizing, and storing useable forms of energy derived from food. Generally, this represents about 10% of TEE, although the thermic effect of food is known to vary in response to the nutrient composition of the meal. The third component of TEE is physical activity energy expenditure. This component is the most variable, as persons can make a conscious decision to be inactive, moderately active, or very active and the resulting influence on TEE can be small to significant.

Expressions of Energy Expenditure

To assist with the quantification of physical activity, other expressions of energy expenditure have been established based on these components of energy expenditure. Energy expended in various forms of physical activity or exercise is often expressed in metabolic equivalents (METs). A MET is a numerical value that represents a multiple of RMR for a specific activity. The Compendium of Physical Activities is a valuable reference that provides MET values for a large selection of physical activities (59). Activities with MET values between 1.0 and 1.5 are considered sedentary. MET

Table 1. Dietary Reference Intake predictive equations for estimating total daily energy expenditure of normal, overweight, and obese adults aged >19 years[a]

Subject	Equation	PA[b]
Men	TEE[c] = $864-(9.72\times$age, y$)+$PA$[(14.2\times$weight, kg$)+(503\times$height, m$)]$	1.00 if PAL[d] is estimated to be ≥1.0 and <1.4 (sedentary)
		1.12 if PAL is estimated to be ≥1.4 and <1.6 (low active)
		1.27 if PAL is estimated to be ≥1.6 and <1.9 (active)
		1.54 if PAL is estimated to be ≥1.9 and <2.5 (very active)
Women	TEE = $387-(7.31\times$age, y$)+$PA$[(10.9\times$weight, kg$)+(660.7\times$height, m$)]$	1.00 if PAL is estimated to be ≥1.0 and <1.4 (sedentary)
		1.14 if PAL is estimated to be ≥1.4 and <1.6 (low active)
		1.27 if PAL is estimated to be ≥1.6 and <1.9 (active)
		1.45 if PAL is estimated to be ≥1.9 and <2.5 (very active)

[a]From the Dietary Reference Intakes (51).
[b]PA = physical activity.
[c]TEE = total energy expenditure.
[d]PAL = physical activity level.

values ranging between 2.0 and 12.0 represent the typical physical activity spectrum from light to moderate to intense, such as strolling at a very slow pace (2 METs) to walking at a brisk pace (4.5 METs) to jogging at a pace of 10 minutes per mile (10 METs). In general, physical activities performed at moderate intensity, as recommended for health benefits, fall in the range of 3.0 to 4.5 METs. Although the MET value applies to the level of energy expenditure achieved during the performance of a specific activity, engaging in different types of physical activities for different durations and different intensities during a 24-hour period is often expressed as the physical activity level. Physical activity level is defined as the ratio of TEE to RMR. In the absence of a direct measurement of total energy expenditure, physical activity level can be estimated as a weighted average of MET values assigned to all activities constituting the 24-hour period, including sleep and rest. Activity levels are often classified as sedentary, low, active, and very active; the corresponding physical activity level values for these activity classifications are listed in Table 1.

TOOLS FOR MEASURING ENERGY EXPENDITURE

TEE

The doubly labeled water stable isotope method is considered the gold-standard for measuring TEE of free-living people (60). It involves the administration of two stable isotopes, deuterium and oxygen-18, and the tracking of their elimination rates from the body. The advantage of this procedure is that it provides an accurate assessment of TEE without modifying the usual lifestyle of the persons being studied. However, accuracy of the technique is dependent on maintenance of body weight during the measurement period. Limitations of the doubly labeled water method include high cost (about $1,500/person) as well as the need for specialized equipment and expertise to implement the technique.

The 2002 Dietary Reference Intake Committee (51) devised TEE predictive equations based on published doubly labeled water data for 407 normal-weight and overweight/obese adults (Table 1). From this information, a physical activity level was calculated by dividing TEE by measured basal energy expenditure. Separate predictive equations were developed for adult men and women from age, height, weight, and physical activity level. Data were not used if the physical activity level value was <1.0 or >2.5. The resulting equations are suitable for prediction of energy requirements for normal-weight groups, overweight/obese groups, and in mixed groups containing normal-weight and overweight/obese adults. These equations have not been subjected to validation studies, but are provided in this manuscript for information.

BMR or RMR

For the determination of oxygen consumption and carbon dioxide production, respiratory gas exchange is measured by sampling expired breath and analyzing its oxygen and carbon dioxide content. Instrumentation used for this procedure is listed in Table 2. This analysis yields a rate of oxygen consumption (VO_2) and a rate of carbon dioxide production (VCO_2). To convert VO_2 and VCO_2 to units of energy expenditure (kilocalories per minute), the Weir equation (61) is used:

$$\text{Kcal/min}=(3.941\times VO_2)+(1.106\times VCO_2)-(2.17\times \text{urinary nitrogen}).$$

VO_2 and VCO_2 units are liters per minute and urinary nitrogen unit is grams per minute.

A difficulty inherent with this calculation is choosing when, and for what period of time, a representative urine sample should be obtained. Fortunately, under normal physiologic and dietary conditions, the contribution of urinary nitrogen is negligible, and a modified Weir equation can be used without introducing any appreciable error:

$$\text{Kcal/min}=(3.9\times VO_2)+(1.1\times VCO_2).$$

An inexpensive alternative to using indirect calorimetry for the determination of BMR or RMR is the use of predictive equations based on simple measures of a person's age, height, and weight (Table 3). Of these equations, the Mifflin equation appears to provide the most accurate predictive power for nonobese persons, with about 80% of predictions accurate within ±10% of measured values. The Harris-Benedict equations tend to overpredict RMR, and the Owen equations tend to underpredict RMR (62). The World Health Organization equations have not undergone rigorous evaluation, although a small study of European adults suggests their predictive power is accurate compared to the BMR determined by a metabolic cart (63).

Physical Activity Energy Expenditure

Measuring physical activity has proved to be a challenging effort due, in part, to the multifaceted nature of movement as well as the limitations of self-report. Both the objective measurement of the different dimensions of motion (type, duration, intensity) and the subjective reporting of activity are prone to error. In an attempt to improve the accuracy of physical activity measurement, investigators often combine two or more methods (examples are listed in Welk [64]). Thus, the limitations of one method can be offset by the strengths of another method. For example, a questionnaire may provide insight into the physical activity pattern that the person considers important and desirable, while a motion sensor worn by this same person provides an actual measure of his or her activity. The synthesis of these results can help guide the development and progress of a physical activity treatment program. Combining methods may also reduce physical activity measurement error when changes in activity are expected to be small and difficult to detect. Table 2 summarizes the advantages and limitations of using each method. Included are selected references from the extensive body of literature evaluating the accuracy of specific devices; however, few studies have assessed the aspect of usability.

Self-Report. Self-report methods for describing physical activity include questionnaires, interviews, and activity diaries. The spectrum of self-report instruments is broad, ranging from simple one-page questionnaires that assess average physical activity during the past year, to labor-intensive diaries that provide a detailed account of activities throughout the day. Questionnaires and interviews often measure occupational and leisure activity separately and assign scores to answers that are then converted to general activity levels or specific energy expenditure values. Black (65) has written guidelines for using information derived from questionnaires to select an appropriate physical activity level factor in calculating TEE. Large-scale epidemiologic studies that seek to determine the relationship between activity and health typically use telephone and/or computer-assisted surveys or written questionnaires to characterize habitual physical activity in a population (66). In contrast, dietitians working with individual clients might use physical activity logs to monitor clients' success in reaching physical activity goals. When selecting among self-report methods, it is important to consider the time and effort required in scoring or evaluating the questionnaire or diary. Questionnaires tend to require little time, whereas diaries are more labor intensive. Reviews addressing the accuracy, repeatability, and utility of self-report physical activity measures are available (67-69). Pereira and colleagues (70) have compiled a comprehensive collection of physical activity questionnaires.

Motion Sensors. Motion sensors comprise a variety of electronic and mechanical devices that include pedometers (step counters) and accelerometers (acceleration detectors). Accelerometers detect total body displacement in a particular plane of motion. Uniaxial or biaxial accelerometers measure motion in the vertical plane while triaxial accelerometers record movement in the vertical, horizontal, and mediolateral planes. Selecting an appropriate sensor for a particular purpose requires forethought of the outcomes to be assessed, in addition to considerations of cost, computer access (accelerometers require computerized data calculation), and subject burden. For example, if accurate estimation of physical activity energy expenditure is being quantified in a small group of highly motivated research subjects, accelerometers positioned on several parts of the body might be optimal. On the other hand, if the effectiveness of an intervention to increase walking is being assessed in an outpatient clinic setting, pedometers would likely suffice. Although subjects demonstrate high compliance in using accelerometers (71), there is considerable variability in performance among models of both accelerometers and pedometers, and investigation is recommended before selecting a device. Summaries of accelerometry, including validation and reliability studies, are available (64,72).

Physiologic Response Measurement. Measurable indicators of the physiologic response to physical activity include heart rate and pulmonary gas exchange. Heart rate monitoring is one of the more common methods used to describe the intensity and duration of physical activity. Today, most monitors have software for converting heart rate data into an estimate of energy expenditure. However, when a higher level of data accuracy is desired, a submaximal, graded exercise test is required to calibrate the subject's heart rate to simultaneous oxygen consumption. From this, a calibration curve can be constructed for estimating energy expenditure at moderate to strenuous levels of exercise: heart rate increases linearly with oxygen consumption (73). A limitation of employing heart rate as a surrogate for energy expenditure is that the relationship between heart rate and VO_2 is weak at low activity levels, which are the levels characteristic of most sedentary individuals. For example, in a seated subject heart rate can rise or fall solely in response to emotions, caffeine intake, ambient temperature, or illness (74). Another important consideration before using heart rate monitors for physical activity assessment is usability. In a recent study measuring physical activity across a 2-week period, highly motivated subjects showed poor compliance in wearing a heart rate monitor for all waking hours on select days (71). Suggested reviews of heart rate monitoring as a marker for physical activity are available (67,72,75).

New Developments. Several recently developed instruments that capture information on physical activity have potential as research tools. A digital activity log developed at the US Department of Agriculture's Western Human Nutrition Research Center allows subjects to record throughout the day the type and duration of physical activities performed. The activity log program, which is derived from a previously published method by Bouchard and colleagues (76), is loaded onto a handheld computer. The user reports activity on an hourly basis, selecting from seven categories of activity (based on METs) and recalling the time spent in those activities in increments as small as 5 minutes. This device holds

Table 2. Resting metabolic rate (RMR) and physical activity measurement tools

Method	Examples	Advantages	Limitations
RMR by indirect calorimetry			
I. Metabolic cart (89)	ParvoMedics (www.parvomedics.com) SensorMedics (www.sensormedics.com) Vacumed (www.vacumed.com)	Automated flow/volume and gas analyses Ability to calibrate instrument before each test Enables minute-by-minute monitoring of test Widely used	Large instrument with limited mobility; not feasible for field use Requires laboratory facilities and skilled personnel for calibration and testing Requires approximately 30 minutes for calibration and test High cost
II. Handheld Device (78,86,87,90)	BodyGem/MedGem (www.healthetech.com)	Small, lightweight, portable Generates result in 8 to 10 minutes Less costly vs cart	Validation studies show significant difference from cart (±90 kcal) Not able to monitor throughout the test (single result provided at end of test)
III. Douglas Bag (91)	Bags available through various vendors; used in conjunction with Tissot spirometer and gas analyzer	Historically considered the gold standard; reliable, valid Low cost	Possible contamination of collected air Separate collection and analysis more time-consuming
Physical Activity			
I. Self-report (70, 74)	Self-administered questionnaire Interviewer-administered questionnaire	Low cost for simple questionnaire Minimal subject burden Captures qualitative and quantitative information	Subjective measure of PA[a] Misinterpretation of instructions Deliberate misreporting Inaccurate recall of intensity and time of PA Some questionnaires fail to capture aspects of PA (eg, frequency, type, duration, intensity)
	PA diary	Captures qualitative & quantitative information	Subjective measure of PA Heavy subject burden Considerable labor cost for converting activity information to energy expenditure
II. Motion sensors	Pedometers Yamax Digiwalker (www.stepintohealth.com) (92,93)	Objective measure of the most common PA Low cost Minimal subject burden Feedback to wearer	Fails to capture nonlocomotor movement Fails to capture intensity and rate of activity Not sensitive to gait differences among people Considerable variability in accuracy among models
	Accelerometers CSA/MTI (www.mtiactigraph.com) Actical (www.mini/mitter.com) Tritrac (www.stayhealthy.com) (94,95)	Objective assessment of PA Data downloaded to computer for analysis Small size, lightweight Minimal subject burden Able to collect data for prolonged period of time Captures information on intensity, frequency, duration of PA	Fails to capture some PA (eg, carrying load, upper body movement [if worn on hip]) Does not differentiate types of activity Moderate to high cost Most models offer no feedback to wearer
III. Physiological Response Measurement (75)	Heart Rate Monitors: Polar (www.polarheartrate-monitor.com)	Objective measure of PA Data downloaded to computer for analysis Direct measure of physiological response to PA Strong correlation with energy expenditure during aerobic PA Captures information on intensity, frequency, duration of PA Feedback to wearer	Heart rate fluctuations may result from non-PA events (eg, emotions, room temp, training) Calibration requires treadmill exercise test Moderate cost Discomfort of wearing chest transmitter over time Signal transmission prone to interference Not useful for capturing energy expenditure of anaerobic activity Multiple methods of analyzing data, yielding different results

(*continued*)

Table 2. Resting metabolic rate (RMR) and physical activity measurement tools (continued)			
Method	**Examples**	**Advantages**	**Limitations**
IV. Recent Developments	Digital Activity Log (www.whnrc.usda.gov) (71,77,78)	Simple to use Modest cost (ie, purchase of handheld computer) Data downloaded to computer for analysis	Subjective measure Moderate subject burden (ie, hourly entries) No feedback to user
	IDEEA (www.minisun.com) (79)	Objective measure of PA Data downloaded to computer for analysis Wide range of data output: type, duration, intensity of PA	Heavy subject burden High cost No feedback to wearer
	Cosmed K4b2 (www.cosmed.it) (85)	Portable combination indirect calorimeter–heart rate monitor system Data downloaded to computer for analysis	Heavy subject burden (ie, face mask) Designed for measuring bouts of PA, not continuous daily activity Peer-review validation studies of combination system not available High cost
	SenseWear armband (www.bodymedia.com) (80)	Wireless sensor; gathers data on movement, energy expenditure, steps, duration of PA, skin temperature, heat flux Data downloaded to computer; analyses via website Minimal subject burden	Peer-review validation studies not available High cost

[a]PA=physical activity.

promise as both a self-monitoring device and a research tool. Preliminary data show excellent usability and high accuracy in estimating physical activity energy expenditure when used by motivated, normal-weight women (71,77,78).

Another recent development is a sophisticated system for recording posture and movement, called the Intelligent Device for Energy Expenditure and Activity. This sensor is part of the next generation of accelerometers in that it describes the type as well as the amount of movement. For example, data collected by the Intelligent Device for Energy Expenditure and Activity can show that a person played soccer or climbed stairs for 30 minutes. It is composed of a small device worn on the hip with flexible wire extensions that attach to the feet, legs, and chest. Validity and reliability studies have been conducted with encouraging results (79).

Two advanced-technology introductions to the line of products that measure physiologic parameters for estimating energy expenditure are the SenseWear Armband (BodyMedia Inc, Pittsburgh, PA) and the Cosmed $K4b^2$ (Cosmed, Rome, Italy). The SenseWear Armband is a

Table 3. Prediction equations for metabolic rate by gender using body weight, height, and age		
Author	**Study subjects**	**Equation**
Harris-Benedict (96)	Men	RMR[a]=66+(13.75×weight, kg)+(5.0×height, cm)–(6.76×age, y)
	Women	RMR=655+(9.56×weight, kg)+(1.85×height, cm)–(4.68×age, y)
Mifflin, et al (97)	Men	RMR=(9.99×weight, kg)+(6.25×height, cm)–(4.92×age, y)+5
	Women	RMR=(9.99×weight, kg)+(6.25×height, cm)–(4.92×age, y)−161
Owen, et al (98,99)	Men	RMR=879+(10.2×weight, kg)
	Women	RMR=795+(7.18×weight, kg)
World Health Organization (100)	Men aged 18-30 years	BMR[b]=(15.4×weight, kg)−(27×height, m)+717
	Men aged 30-60 years	BMR=(11.3×weight, kg)+(16×height, m)+901
	Men aged >60 years	BMR=(8.8×weight, kg)+(1,128×height, m)−1,071
	Women aged 18-30 years	BMR=(13.3×weight, kg)+(334×height, m)+35
	Women aged 30-60 years	BMR=(8.7×weight, kg)−(25×height, m)+865
	Women aged >60 years	BMR=(9.2×weight, kg)+(637×height, m)−302

[a]RMR=resting metabolic rate.
[b]BMR=basal metabolic rate.

portable device worn on the upper arm that contains an accelerometer, temperature sensors, and a receiver capable of recording transmissions from a heart rate monitor. Information on validity and reliability of the SenseWear device is available on the manufacturer's Web site (80); no peer-review studies have been published. The Cosmed K4b^2 is a portable system composed of gas (O_2, CO_2) analyzers and a heart rate monitor, designed to estimate physical activity energy expenditure in the field and laboratory. The indirect calorimetry component of the Cosmed has tested well for accuracy and reliability (81-85), but the combination system has yet to be validated.

CONCLUSIONS

Promoting an active lifestyle is critical to stemming the obesity epidemic in the United States. In the current environment, understanding what tools are available to assess physical activity and how to implement and interpret the measurements are essential skills. For health care practitioners engaged in lifestyle counseling as part of their nutrition and health services, personalization of energy requirements through the use of the tools described in this review could add an exciting dimension to their practice. Often, a client's interest is stimulated and motivation elevated when personalized information is provided. This can lead to better compliance with the prescribed dietary and/or exercise regimen. Measured RMR and/or physical activity level can also assist in tailoring a weight-loss or weight-maintenance diet to a client's specific needs. For health care professionals in private practice, the addition of these tools could expand client bases. Many healthy clients are interested in seeking out professional services to better understand their personal energy requirements for lifetime health. Some of these tools could also provide objective and scientific measurements of physical activity and energy expenditure for nutrition and/or dietetics outcomes-based research.

PRACTICE POINTS

Personalize a client's therapy by using the appropriate tools to estimate or measure energy expenditure. This will enhance the effectiveness of services by engaging and motivating the person and incorporating individualized measurements.

Approaches for Determining RMR

Estimated RMR. Assess the level of accuracy of energy expenditure needed for the intended use. This means that if an equation will satisfy your purpose, it is the most cost-effective approach. However, it should be kept in mind that the equations are accurate for only approximately 80% of individuals at best (refer to the previous RMR sections for accuracy and appropriateness of equations). If this is not acceptable, use a more precise method, such as measuring RMR.

Measured RMR. This approach requires a metabolic cart, handheld device, or Douglas bag. The handheld device has been shown to be accurate within ±90 kcal of the cart measurement (86,87). This finding, plus the cost and availability of equipment, will determine your choice of instrument. Also consider the stringency of test conditions before and during the measurement of RMR. For example, if the RMR will be used for research, a stringent protocol ought to be implemented. In contrast, if the RMR will be used to guide a person in weight loss, a clinical level protocol may be followed (see the previous RMR section for guidance).

Four Suggested Approaches for Determining TEE

The Dietary Reference Intake equations (Table 1) are derived from doubly labeled water data and are likely to yield a fairly accurate prediction of TEE in healthy adults. However, in addition to age, weight, and height, an estimate of physical activity level is required for the calculation. This could be derived from a questionnaire (such as the Baecke Physical Activity Questionnaire [88]). With this approach, the physical activity level calculated from the questionnaire is interpreted by referring to Black (65).

TEE=RMR×physical activity level, where RMR is measured and physical activity level is determined from a questionnaire. Although this approach does not include the thermic effect of food, it provides a fairly accurate estimation of TEE (78).

TEE=[RMR (measured) (No. of waking hours)]+physical activity (accelerometer)+estimated sleeping energy expenditure. The sleep component is calculated as (RMR×0.9) (No. of sleep hours). This approach requires a measured RMR plus access to or purchase of accelerometers and computer hardware/software to translate recorded accelerometer motion to energy expenditure. To reduce costs, several accelerometers can be purchased and rotated. Although accelerometers have been found to be highly user friendly (71), some tend to underestimate moderate-intensity activity. This might explain the underestimation of TEE found in a recent study using this approach (78). As noted, this equation does not include thermic effect of food.

TEE=[RMR (measured) (No. of waking hours)]+PA (digital activity log)+estimated sleeping energy expenditure. This approach provides the advantage of calculating TEE while also capturing categories of activities (seated quietly, moderate sport) performed throughout the day. The hours spent in various MET-level categories are utilized to calculate TEE from the digital activity log. Sleeping metabolic rate can be estimated at (RMR×0.9) (No. of sleep hours). This method has recently been validated and shown to be within 10% of TEE as determined by the doubly labeled water method when used by motivated, normal-weight women (78). Further information about the digital activity log can be obtained at the Western Human Nutrition Research Center Website (www.whnrc.usda.gov).

Mention of a trademark or proprietary product does not constitute endorsement by the US Department of Agriculture and does not imply recommendation over others that may be suitable.

References

1. Mokdad AH, Marks JS, Stroup DF, Gerberding JL. Actual causes of death in the United States, 2000. *JAMA*. 2004;291:1238-1245.
2. McGinnis JM, Foege WH. Actual causes of death in the United States. *JAMA*. 1993;270:2207-2212.
3. Paffenbarger RS Jr, Hyde RT, Wing AL, Hsieh CC.

Physical activity, all-cause mortality, and longevity of college alumni. *N Engl J Med*. 1986;314:605-613.
4. Paffenbarger RS Jr, Hyde RT, Jung DL, Wing AL. Epidemiology of exercise and coronary heart disease. *Clin Sports Med*. 1984;3:297-318.
5. *Nutrition and Your Health: Dietary Guidelines for Americans, 2000.* 5th ed. Washington, DC: US Government Printing Office; 2000. Home and Garden Bulletin No. 232.
6. King NA, Tremblay A, Blundell JE. Effects of exercise on appetite control: Implications for energy balance. *Med Sci Sports Exerc*. 1997;29:1076-1089.
7. Faulkner RA, Green HJ, White TP. Response and adaptation of skeletal muscle to changes in physical activity, In: Bouchard C, Shephard RJ, Stephens T, eds. *Physical Activity, Fitness, and Health. International Proceedings and Consensus Statement*. Champaign, IL: Human Kinetics; 1994:343-357.
8. Despres J-P. Physical activity and adipose tissue. In: Bouchard C, Shephard RJ, Stephens T, eds. *Physical Activity, Fitness, and Health*. Champaign, IL: Human Kinetics; 1994:358-368.
9. Araujo-Vilar D, Osifo E, Kirk M, Garcia-Estevez DA, Cabezas-Cerrato J, Hockaday TD. Influence of moderate physical exercise on insulin-mediated and non-insulin-mediated glucose uptake in healthy subjects. *Metabolism*. 1997;46:203-209.
10. Helmrich SP, Ragland DR, Leung RW, Paffenbarger RS Jr. Physical activity and reduced occurrence of non-insulin-dependent diabetes mellitus. *N Engl J Med*. 1991;325:147-152.
11. Manson JE, Rimm EB, Stampfer MJ, Colditz GA, Willett WC, Krolewski AS, Rosner B, Hennekens CH, Speizer FE. Physical activity and incidence of non–insulin-dependent diabetes mellitus in women. *Lancet*. 1991;338:774-778.
12. Manson JE, Nathan DM, Krolewski AS, Stampfer MJ, Willett WC, Hennekens CH. A prospective study of exercise and incidence of diabetes among US male physicians. *JAMA*. 1992;268:63-67.
13. Knowler WC, Barrett-Connor E, Fowler SE, Hamman RF, Lachin JM, Walker EA, Nathan DM. Reduction in the incidence of type 2 diabetes with lifestyle intervention or metformin. *N Engl J Med*. 2002;346:393-403.
14. Tuomilehto J, Lindstrom J, Eriksson JG, Valle TT, Hamalainen H, Ilanne-Parikka P, Keinanen-Kiukaanniemi S, Laakso M, Louheranta A, Rastas M, Salminen V, Uusitupa M. Prevention of type 2 diabetes mellitus by changes in lifestyle among subjects with impaired glucose tolerance. *N Engl J Med*. 2001;344:1343-1350.
15. Horton ES. Exercise and physical training: Effects on insulin sensitivity and glucose metabolism. *Diabetes Metab Rev*. 1986;2:1-17.
16. Mayer-Davis EJ, D'Agostino R Jr, Karter AJ, Haffner SM, Rewers MJ, Saad M, Bergman RN. Intensity and amount of physical activity in relation to insulin sensitivity: The Insulin Resistance Atherosclerosis Study. *JAMA*. 1998;279:669-674.
17. Bergman BC, Butterfield GE, Wolfel EE, Lopaschuk GD, Casazza GA, Horning MA, Brooks GA. Muscle net glucose uptake and glucose kinetics after endurance training in men. *Am J Physiol* 1999;277:E81-E92.
18. Horton ES. Exercise and decreased risk of NIDDM. *N Engl J Med*. 1991;325:196-198.
19. Richter EA, Ruderman NB, Schneider SH. Diabetes and exercise. *Am J Med*. 1981;70:201-209.
20. Huttunen JK, Lansimies E, Voutilainen E, Ehnholm C, Hietanen E, Penttila I, Siitonen O, Rauramaa R. Effect of moderate physical exercise on serum lipoproteins. A controlled clinical trial with special reference to serum high-density lipoproteins. *Circulation*. 1979; 60:1220-1229.
21. Williams PT, Krauss RM, Vranizan KM, Wood PD. Changes in lipoprotein subfractions during diet-induced and exercise-induced weight loss in moderately overweight men. *Circulation*. 1990;81:1293-1304.
22. Williams PT, Krauss RM, Vranizan KM, Albers JJ, Wood PD. Effects of weight-loss by exercise and by diet on apolipoproteins A-I and A-II and the particle-size distribution of high-density lipoproteins in men. *Metabolism*. 1992;41:441-449.
23. Williams PT. Relationship of distance run per week to coronary heart disease risk factors in 8283 male runners. The National Runners' Health Study. *Arch Intern Med*. 1997;157:191-198.
24. Arroll B, Beaglehole R. Does physical activity lower blood pressure: A critical review of the clinical trials. *J Clin Epidemiol*. 1992;45:439-447.
25. El-Sayed MS. Effects of exercise on blood coagulation, fibrinolysis and platelet aggregation. *Sports Med*. 1996;22:282-298.
26. Hinkle LE Jr, Thaler HT, Merke DP, Renier-Berg D, Morton NE. The risk factors for arrhythmic death in a sample of men followed for 20 years. *Am J Epidemiol*. 1988;127:500-515.
27. Press V, Freestone I, George CF. Physical activity: the evidence of benefit in the prevention of coronary heart disease. *Q J Med*. 2003;96:245-251.
28. Bouchard C. *Physical Activity, Fitness, and Health*. Champaign, IL: Human Kinetics; 1994.
29. *Physical Activity and Health: A Report of the Surgeon General*. Mental Health. Washington, DC: US Dept of Health and Human Services; 1996:135-141.
30. Dunn AL, Trivedi MH, O'Neal HA. Physical activity dose-response effects on outcomes of depression and anxiety. *Med Sci Sports Exerc*. 2001;33(6 suppl): S587-597.
31. Martinsen EW. Physical activity and depression: Clinical experience. *Acta Psychiatr Scand Suppl*. 1994;377:23-27.
32. Paluska SA, Schwenk TL. Physical activity and mental health: Current concepts. *Sports Med*. 2000; 29:167-180.
33. Churchill JD, Galvez R, Colcombe S, Swain RA, Kramer AF, Greenough WT. Exercise, experience and the aging brain. *Neurobiol Aging*. 2002;23:941-955.
34. Colcombe S, Kramer AF. Fitness effects on the cognitive function of older adults: A meta-analytic study. *Psychol Sci*. 2003;14:125-130.
35. Anderson BJ, Rapp DN, Baek DH, McCloskey DP, Coburn-Litvak PS, Robinson JK. Exercise influences spatial learning in the radial arm maze. *Physiol Behav*. 2000;70:425-429.

36. Black JE, Isaacs KR, Anderson BJ, Alcantara AA, Greenough WT. Learning causes synaptogenesis, whereas motor activity causes angiogenesis, in cerebellar cortex of adult rats. *Proc Natl Acad Sci U S A*. 1990;87:5568-5572.
37. Neeper SA, Gomez-Pinilla F, Choi J, Cotman C. Exercise and brain neurotrophins. *Nature*. 1995;373:109.
38. Cotman CW, Berchtold NC. Exercise: A behavioral intervention to enhance brain health and plasticity. *Trends Neurosci*. 2002;25:295-301.
39. *Exercise Testing and Training of Apparently Healthy Individuals: A Handbook for Physicians*. New York, NY: The American Heart Association: 1972.
40. American College of Sports Medicine position statement on the recommended quantity and quality of exercise for developing and maintaining fitness in healthy adults. *Med Sci Sports*. 1978;10:vii-x.
41. American College of Sports Medicine Position Stand. The recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness, and flexibility in healthy adults. *Med Sci Sports Exerc*. 1998;30:975-991.
42. *Healthy People: The Surgeon General's Report on Health Promotion and Disease Prevention*. Rockville, MD: US Department of Health, Education, and Welfare; 1979.
43. *The Surgeon General's Report on Nutrition and Health*. Washington, DC: US Dept of Health and Human Services, Public Health Service; 1988.
44. Jakicic JM, Clark K, Coleman E, Donnelly JE, Foreyt J, Melanson E, Volek J, Volpe SL. American College of Sports Medicine position stand. Appropriate intervention strategies for weight loss and prevention of weight regain for adults. *Med Sci Sports Exerc*. 2001;33:2145-2156.
45. Jakicic JM, Winters C, Lang W, Wing RR. Effects of intermittent exercise and use of home exercise equipment on adherence, weight loss, and fitness in overweight women: A randomized trial. *JAMA*. 1999;282:1554-1560.
46. Schoeller DA, Shay K, Kushner RF. How much physical activity is needed to minimize weight gain in previously obese women? *Am J Clin Nutr*. 1997; 66:551-556.
47. Votruba SB, Horvitz MA, Schoeller DA. The role of exercise in the treatment of obesity. *Nutrition*. 2000; 16:179-188.
48. Pronk NP, Wing RR. Physical activity and long-term maintenance of weight loss. *Obes Res*. 1994;2:587-599.
49. Jakicic JM. The role of physical activity in prevention and treatment of body weight gain in adults. *J Nutr*. 2002;132:3826S-3829S.
50. Saris W, Blair SN, van Baak MA, Eaton SB, Davies PSW, DiPietro L, Fogelholm M, Rissanen A, Schoeller DA, Swinburn B, Tremblay A, Westerterp K, Wyatt H. How much physical activity is enough to prevent unhealthy weight gain? Outcome of the IASO 1st Stock Conference and consensus statement. *Obes Rev*. 2003;4:101-114.
51. Institute of Medicine, Food and Nutrition Board. *Dietary Reference Intakes for Energy, Carbohydrate, FIber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids (Macronutrients)*. Prepublication available at: www.nap.edu/catalog/10490.html. Accessed June 20, 2004.
52. Tucker LA, Friedman GM. Television viewing and obesity in adult males. *Am J Public Health*. 1989; 79:516-518.
53. Tucker LA, Bagwell M. Television viewing and obesity in adult females. *Am J Public Health*. 1991;81: 908-911.
54. Hu FB, Leitzmann MF, Stampfer MJ, Colditz GA, Willett WC, Rimm EB. Physical activity and television watching in relation to risk for type 2 diabetes mellitus in men. *Arch Intern Med*. 2001;161:1542-1548.
55. Hu FB, Li TY, Colditz GA, Willett WC, Manson JE. Television watching and other sedentary behaviors in relation to risk of obesity and type 2 diabetes mellitus in women. *JAMA*. 2003;289:1785-1791.
56. Powell KE, Thompson PD, Caspersen CJ, Kendrick JS. Physical activity and the incidence of coronary heart disease. *Ann Rev Public Health*. 1987; 8:253-287.
57. Salmon J, Bauman A, Crawford D, Timperio A, Owen N. The association between television viewing and overweight among Australian adults participating in varying levels of leisure-time physical activity. *Int J Obes Relat Metab Disord*. 2000;24:600-606.
58. Jeffery RW, Utter J. The changing environment and population obesity in the United States. *Obes Res*. 2003;11(suppl):12S-22S.
59. Ainsworth BE, Haskell WL, Whitt MC, Irwin ML, Swartz AM, Strath SJ, O'Brien WL, Bassett DR Jr, Schmitz KH, Emplaincourt PO, Jacobs DR Jr, Leon AS. Compendium of physical activities: An update of activity codes and MET intensities. *Med Sci Sports Exerc*. 2000;32(suppl 9):S498-S504.
60. Schoeller DA, Ravussin E, Schutz Y, Acheson KJ, Baertschi P, Jequier E. Energy expenditure by doubly labeled water: Validation in humans and proposed calculation. *Am J Physiol*. 1986;250(5 pt 2): R823-R830.
61. Weir J. New methods for calculating metabolic rate with special reference to protein metabolism. *J Physiol*. 1949;109:1-9.
62. *Let the Evidence Speak: Indirect Calorimetry and Weight Management Guides*. Chicago, IL: The American Dietetic Association; 2003.
63. Goris AH, Meijer EP, Kester A, Westerterp KR. Use of a triaxial accelerometer to validate reported food intakes. *Am J Clin Nutr*. 2001;73:549-553.
64. Welk GJ, ed. *Physical Activity Assessments for Health-Related Research*. Champaign, IL: Human Kinetics; 2002.
65. Black AE. Critical evaluation of energy intake using the Goldberg cut-off for energy intake: Basal metabolic rate. A practical guide to its calculation, use and limitations. *Int J Obes Relat Metab Disord*. 2000;24:1119-1130.
66. US Centers for Disease Control and Prevention physical activity surveys. Available at: http://www.cdc.gov/nccdphp/dnpa/physical/physical_surveys.htm. Accessed June 20, 2004.
67. Haskell WL, Kiernan M. Methodologic issues in measuring physical activity and physical fitness when evaluating the role of dietary supplements for physi-

cally active people. *Am J Clin Nutr.* 2000;72(suppl 2):S541-S550.
68. Matthews CE. Use of self-report instruments to assess physical activity. In: Welk GJ, ed. *Physical Activity Assessments for Health-Related Research*. Champaign, IL: Human Kinetics; 2002.
69. Sallis JF, Saelens BE. Assessment of physical activity by self-report: Status, limitations, and future directions. *Res Q Exerc Sport.* 2000;71(suppl 2):S1-S14.
70. Pereira MA, FitzerGerald SJ, Gregg EW, Joswiak ML, Ryan WJ, Suminski RR, Utter AC, Zmuda JM. A collection of Physical Activity Questionnaires for health-related research. *Med Sci Sports Exerc* 1997; 29(suppl 6):S1-S205.
71. Forrest A, Gustafson-Storms M, Gale B, Blanton C, Horn W, Keim N, Kretsch M. Subject compliance using digital activity log, accelerometer and heart rate monitor to record physical activity. *FASEB J*. 2004;18:A112.
72. Ainslie P, Reilly T, Westerterp K. Estimating human energy expenditure: A review of techniques with particular reference to doubly labelled water. *Sports Med*. 2003;33:683-698.
73. Freedson PS, Miller K. Objective monitoring of physical activity using motion sensors and heart rate. *Res Q Exerc Sport.* 2000;71(suppl 2):S21-S29.
74. Montoye HJ. *Measuring Physical Activity and Energy Expenditure*. Champaign, IL: Human Kinetics; 1996.
75. Janz KF. Use of heart rate monitors to assess physical activity. In: Welk GJ, Physical Activity Assessments for Health-Related Research. Champaign, IL: Human Kinetics; 2002
76. Bouchard C, Tremblay A, Leblanc C, Lortie G, Savard R, Theriault G. A method to assess energy expenditure in children and adults. *Am J Clin Nutr*. 1983;37:461-467.
77. Gustafson-Storms M, Forrest A, Gale B, Blanton C, Horn W, Keim N, Kretsch M. Fatigue or learning curve: Do weekly repeated measures improve the quality of physical activity monitoring? *FASEB J*. 2004;18:A113.
78. Kretsch MJ, Blanton CA, Baer D, Staples R, Horn WF, Keim NL. Measuring energy expenditure with simple, low-cost tools. *J Am Diet Assoc.* 2004; 104(suppl 2):A-13.
79. Zhang K, Werner P, Sun M, Pi-Sunyer FX, Boozer CN. Measurement of human daily physical activity. *Obes Res*. 2003;11:33-40.
80. Liden C, Wolowicz M, Stivoric J, Teller A, Vishnubhatla S, Pelletier R, Farringdon J. Accuracy and reliability of the SenseWear armband as an energy expenditure assessment device. Available at: http://www.bodymedia.com. Accessed June 20, 2004.
81. Hausswirth C, Bigard AX, Le Chevalier JM. The Cosmed K4 telemetry system as an accurate device for oxygen uptake measurements during exercise. *Int J Sports Med.* 1997;18:449-453.
82. Lothian F, Farrally MR, Mahoney C. Validity and reliability of the Cosmed K2 to measure oxygen uptake. *Can J Appl Physiol*. 1993;18:197-206.
83. Lucia A, Fleck SJ, Gotshall RW, Kearney JT. Validity and reliability of the Cosmed K2 instrument. *Int J Sports Med*. 1993;14:380-386.
84. McLaughlin JE, King GA, Howley ET, Bassett DR Jr, Ainsworth BE. Validation of the COSMED K4 b2 portable metabolic system. *Int J Sports Med*. 2001; 22:280-284.
85. Maiolo C, Melchiorri G, Iacopino L, Masala S, De Lorenzo A. Physical activity energy expenditure measured using a portable telemetric device in comparison with a mass spectrometer. *Br J Sports Med.* 2003;37:445-447.
86. Blanton C, Gale B, Gustafson-Storms M, Kretsch M. Resting metabolic rate (RMR): Evaluation of a portable handheld device. *FASEB J*. 2004;18:A112.
87. Melanson E, Coelho L, Tran ZV, Haugen H, Kearney JM, Hill J. Validation of the BodyGem hand-held indirect calorimeter. Abstract presented at Nutrition Week 2003, San Antonio, TX, January 18-22, 2003.
88. Baecke JA, Burema J, Fritters ER. A short questionnaire for the measurement of habitual physical activity in epidemiological studies. *Am J Clin Nutr*. 1982;36:936-942.
89. Macfarlane DJ. Automated metabolic gas analysis systems: A review. *Sports Med*. 2001;31:841-861.
90. Nieman DC, Trone GA, Austin MD. A new handheld device for measuring resting metabolic rate and oxygen consumption. *J Am Diet Assoc*. 2003;103:588-592.
91. Consolazio FC. *Physiological Measurements of Metabolic Functions in Man*. New York, NY McGraw-Hill; 1963.
92. Schneider PL, Crouter SE, Bassett DR. Pedometer measures of free-living physical activity: Comparison of 13 models. *Med Sci Sports Exerc*. 2004;36:331-335.
93. Tudor-Locke CE, Myers AM. Methodological considerations for researchers and practitioners using pedometers to measure physical (ambulatory) activity. *Res Q Exerc Sport*. 2001;72:1-12.
94. Bassett DR Jr. Validity and reliability issues in objective monitoring of physical activity. *Res Q Exerc Sport.* 2000;71(suppl 2):S30-S36.
95. Welk GJ, Blair SN, Wood K, Jones S, Thompson RW. A comparative evaluation of three accelerometry-based physical activity monitors. *Med Sci Sports Exerc.* 2000;32(suppl 9):S489-S497.
96. Harris JA, Benedict FG: A biometric study of basal metabolism in men. Washington, DC: Carnegie Institute of Washington; 1919. Publication No. 29(279).
97. Mifflin MD, St Jeor ST, Hill LA, Scott BJ, Daugherty SA, Koh YO. A new predictive equation for resting energy expenditure in healthy individuals. *Am J Clin Nutr.* 1990;51:241-247.
98. Owen OE, Holup JL, D'Alessio DA, Craig ES, Polansky M, Smalley KJ, Kavle EC, Bushman MC, Owen LR, Mozzoli MA. A reappraisal of the caloric requirements of men. *Am J Clin Nutr*. 1987;46:875-885.
99. Owen OE, Kavle E, Owen RS, Polansky M, Caprio S, Mozzoli MA, Kendrick ZV, Bushman MC, Boden G. A reappraisal of caloric requirements in healthy women. *Am J Clin Nutr*. 1986;44:1-19.
100. World Health Organization. *Energy and Protein Requirements*. Geneva, Switzerland: Food and Agricultural Organization/World Health Organization/ United Nations University; 1985.